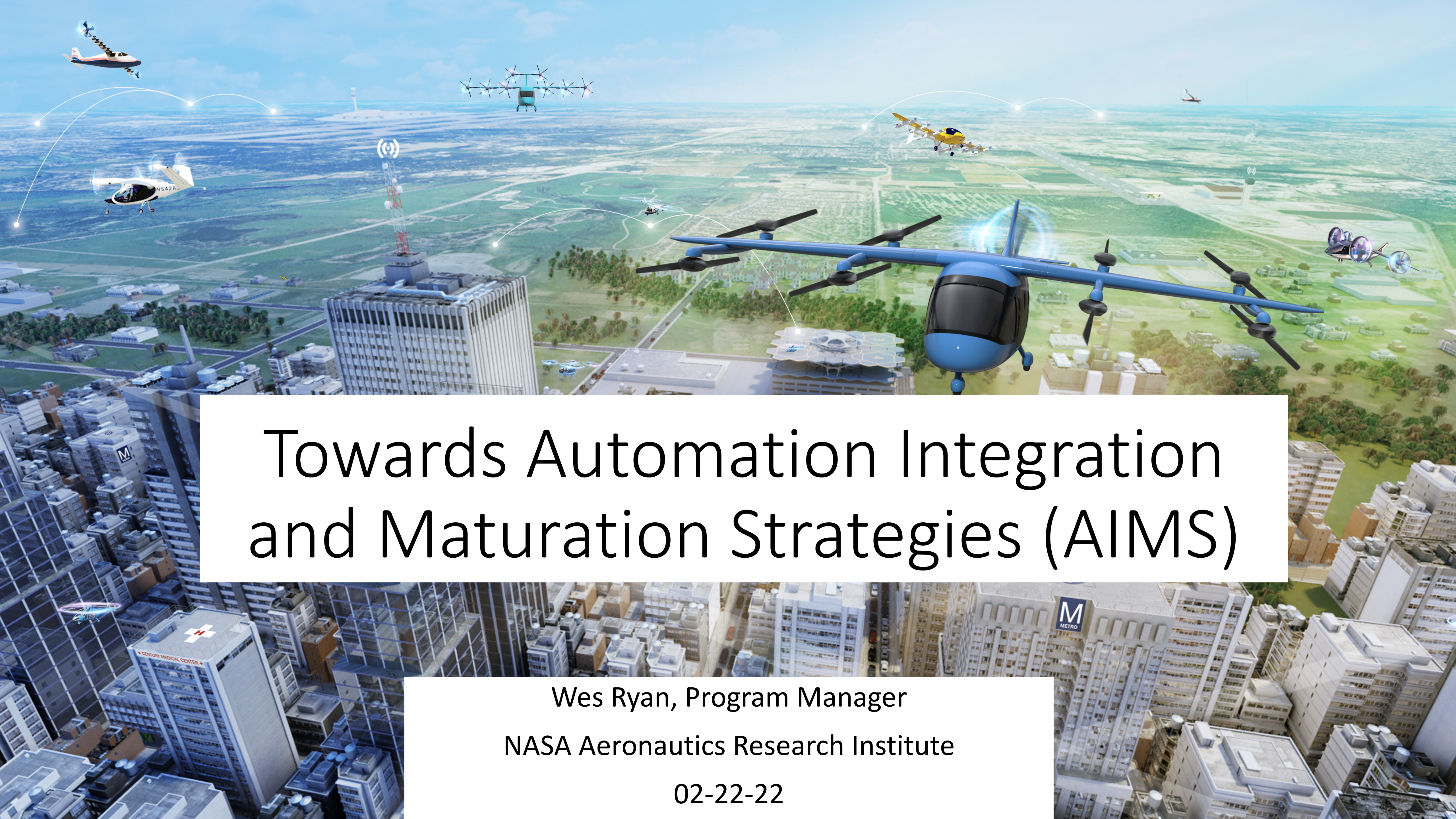


# Towards Automation Integration and Maturation Strategies (AIMS)

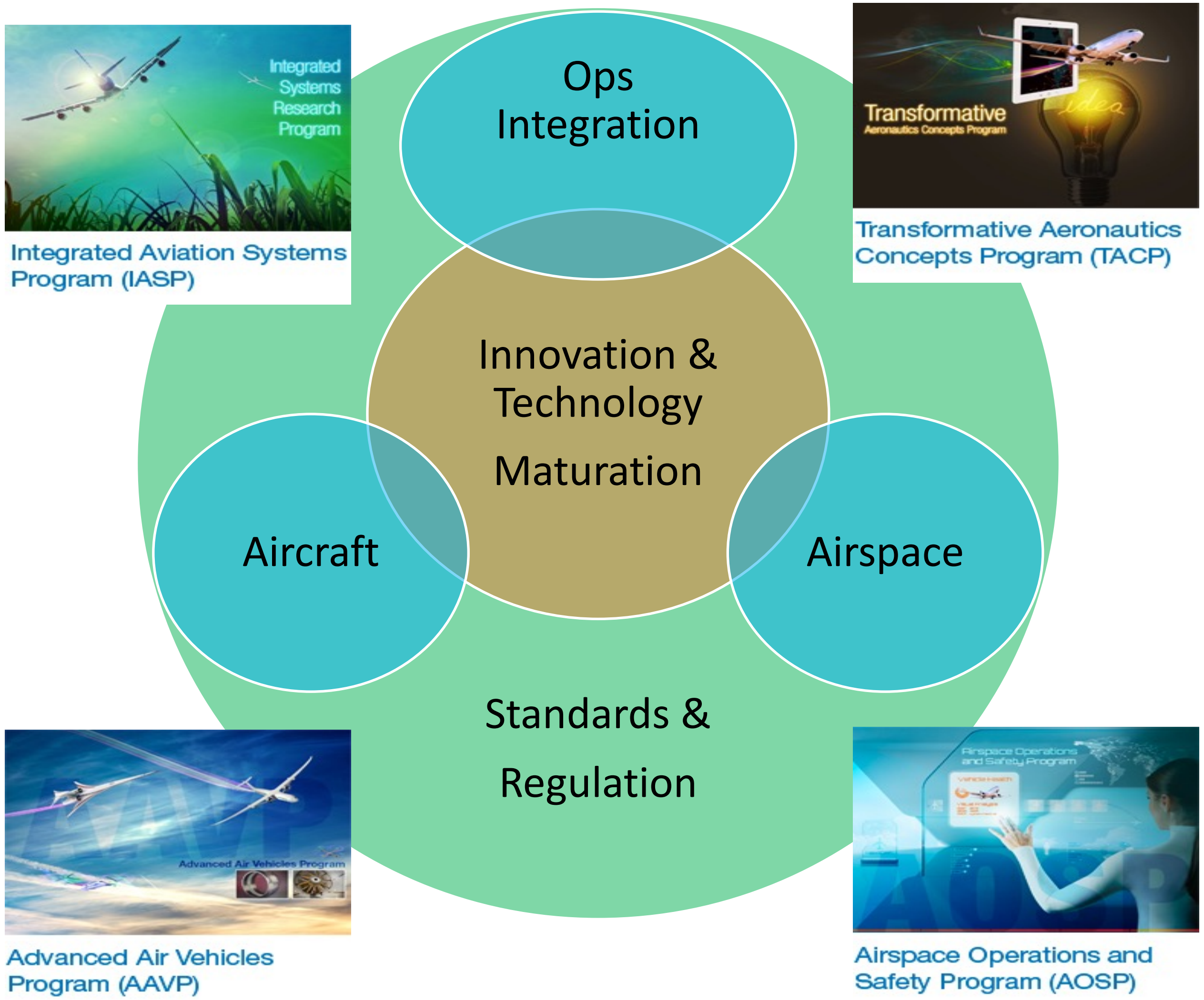

Wes Ryan, Program Manager

NASA Aeronautics Research Institute


02-22-22

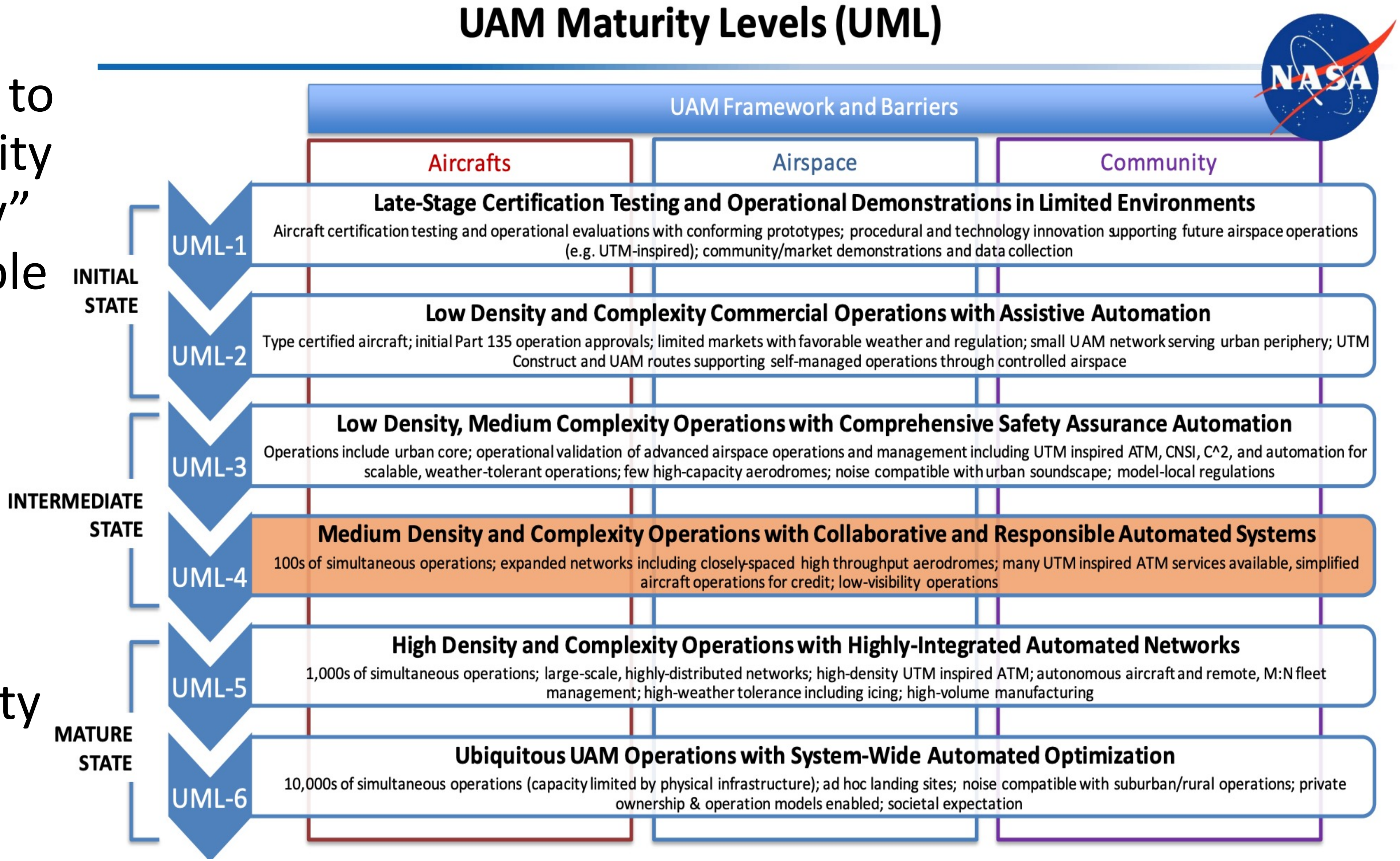
# UAM/AAM Vision Includes Entire Ecosystem

- How Can NASA Assist Industry/FAA to Bridge Gaps Between Future Vision for UAM/AAM and Current Capability?
- Industry Has Many, Independent Efforts, Different CONOPS, and Business Plans – Individually Working with FAA
- Seeking Common Approach to Define and Accelerate New Capabilities for Aircraft, Ops Integration, and Airspace Mgmt

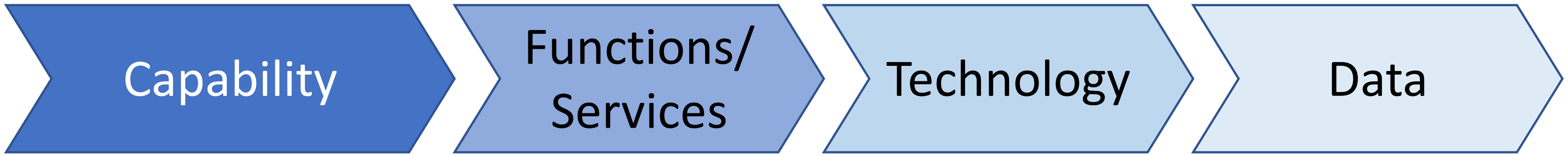


# UML Capabilities

- How do we get to “Medium Density and Complexity” and “Responsible Automated Systems”?
- Methodically Building from Current Capability to Future Capability



# Notional Automation Capability Maturity Model



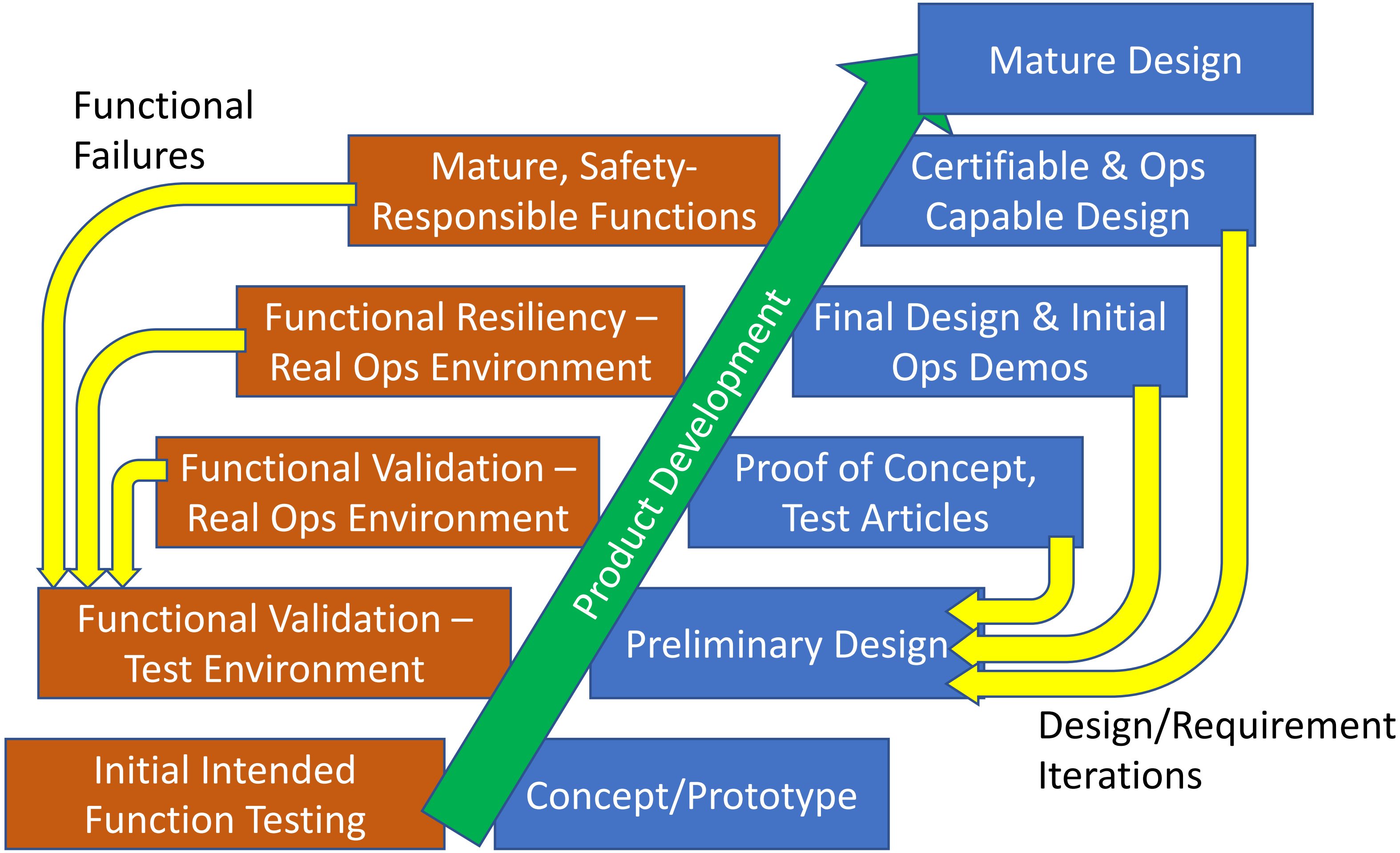

- Capability – a new Ability, Level of Expertise, Level of Proficiency
- Function/Service – Task, Role, and/or Intent of a System to Enable a Capability
- Technology – Equipment & Elements to Implement a Function/Service
- Data/Sensors – Information Sources Required by a Technology to Achieve and Maintain its Function in Support of a Capability
- Cannot Reach a Capability without assessing maturity, integrity, reliability, availability, etc. of data sources & technology to implement an intended function in support of a new capability
  - Must have a clear maturation path from data/sensors, to core technology, to intended function, to mature capability for civil use

# Capability Maturity Model (Simple Example)

| Capability | Function/Service | Technology | Data |
|---|---|---|---|
| Airspace Management | Conflict Detection and Avoidance | Sense and Avoid/DAA, Surveillance, Data Sharing, Trajectory Mgmt | GPS Position, Timing, Intended Trajectory/Plan |
| Aircraft Flight Path Management | 4D Automated Flight Path Control | Digital Flight Controls, Contingency Management Procedures | Aircraft State, Progress Along Intended Trajectory, Sharing Data with ATC |
| Operational Integration | Flight Planning/Approval | Automated Flight Plan Filing, Deconfliction | Intended Path/Timing Relative to Others |
| Capability Assessment by Gated Analysis | | | |
| Is Capability Mature Now? | Is Intended Function to Enable the Capability the Same (Use Case), or are there Changes in Assumptions, Boundary Conditions? | Is Technology Mature, Including Assumed Role of Human and Automation? | Is Data to Feed Technology At the Needed Level of Integrity, Accuracy, Availability, Security, etc. |

# Benefit of Using CMM Concept for Automation

- Methodical Progression from Prototype, to Initial Function with Human Monitoring/Backup, to Safety Responsible Function
- Common Framework for Analyzing Each Step Towards Proven Capability

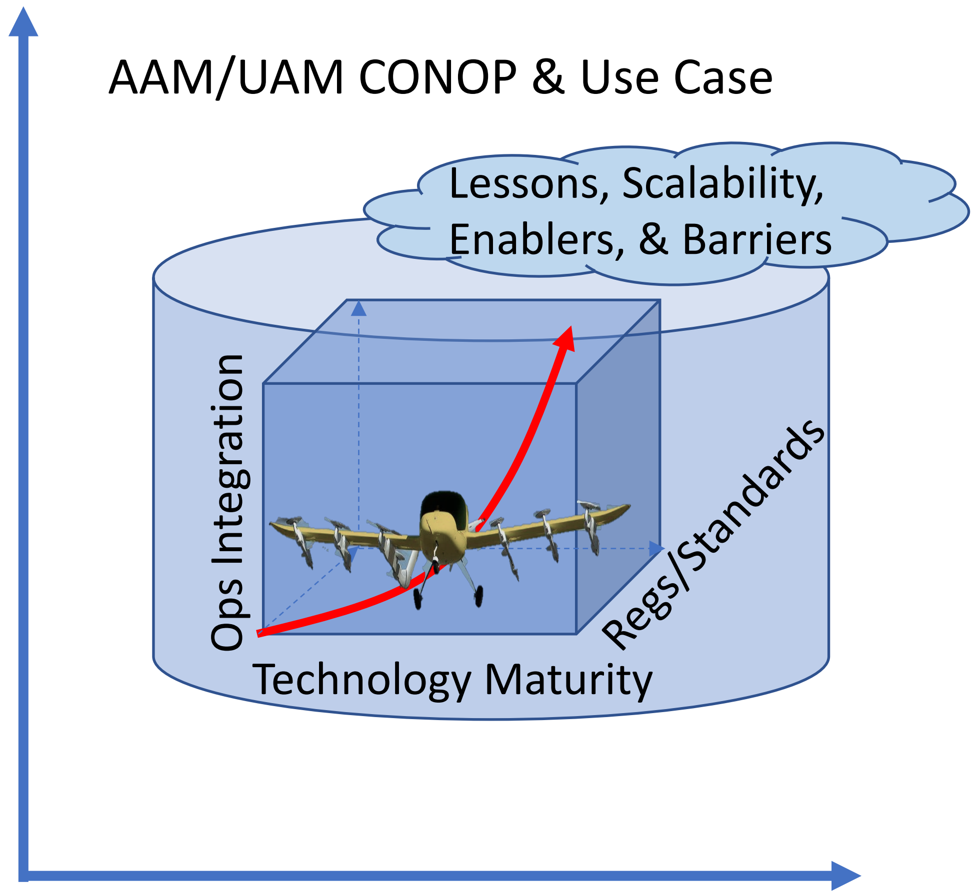


# Capability Maturity Model Outcomes

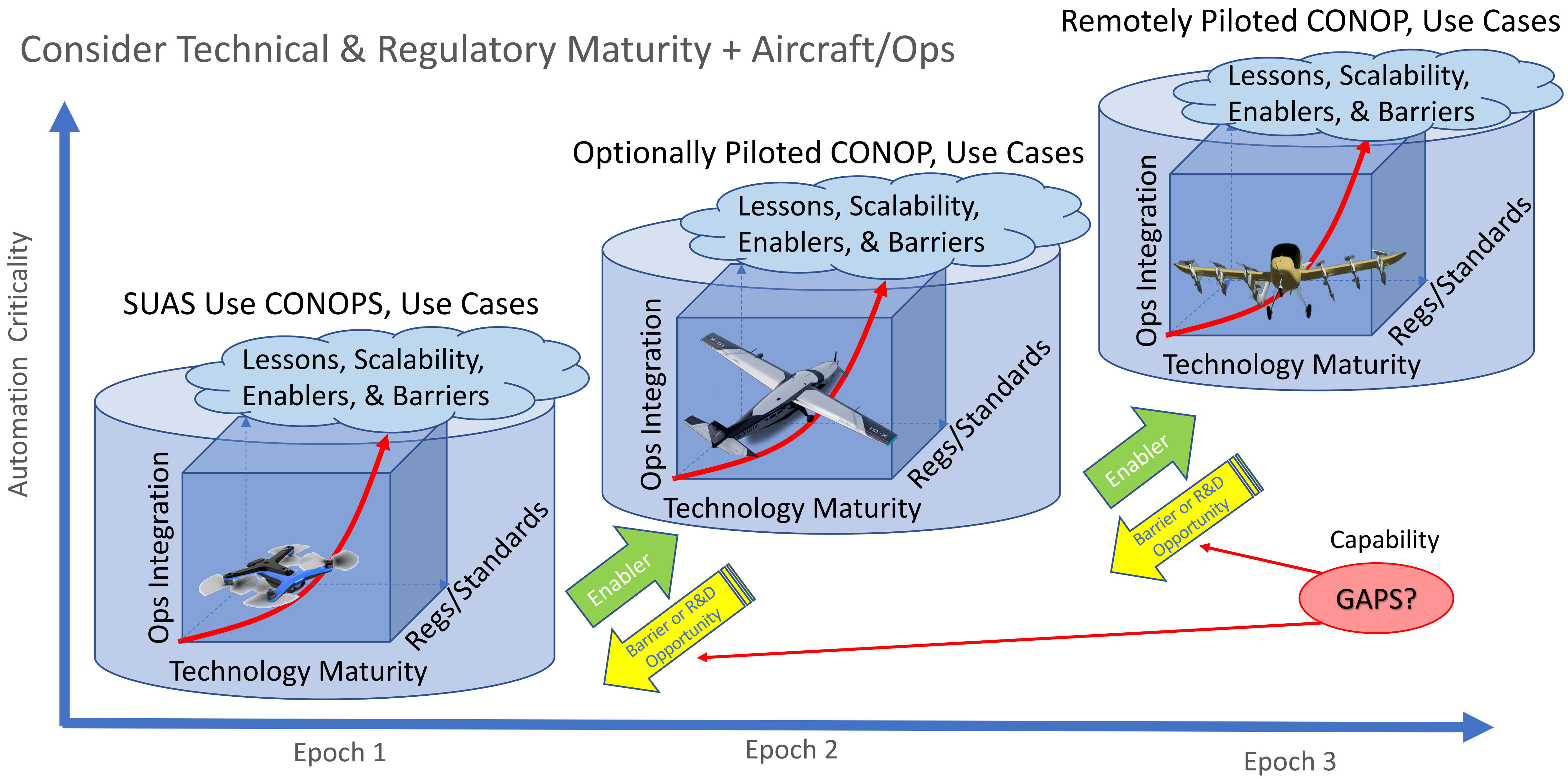
- Common Path - Several CONOPS Focus on Future Operational Automation State Without Path to Get There, e.g. Relying on others for Core Capabilities
- Identify Gaps in Capability – Prototype vs. Mature Technology
- Wholistic Plan - Look Beyond Aircraft Prototype Development to Ops Integration, Robust Life-cycle in Real World
- Target Civil Use - Production Certification, Materials & Civil Safety Expectations, What is Achievable
- Robust System Architecture – Feed MBSE – Accuracy and Assumptions of Simulation Impact Value of Effort

# Capability Maturity Model – CONOP Focus

- Each Use Case Has Different Capabilities/Needs for Technology and Data – AAM, UAM, UAS, Remote Cargo
- Scalability of Technology & Technology Limits Inform Barriers & Enablers for Next "Epoch" or Expanded Use Case
- Lessons Learned Could Inform Other Use Case Evaluations and Technology Maturation/Integration Strategy
- Expanded Use Case Must Consider Technology and Data Gaps
- Regulatory Readiness and Standards Informed by Data

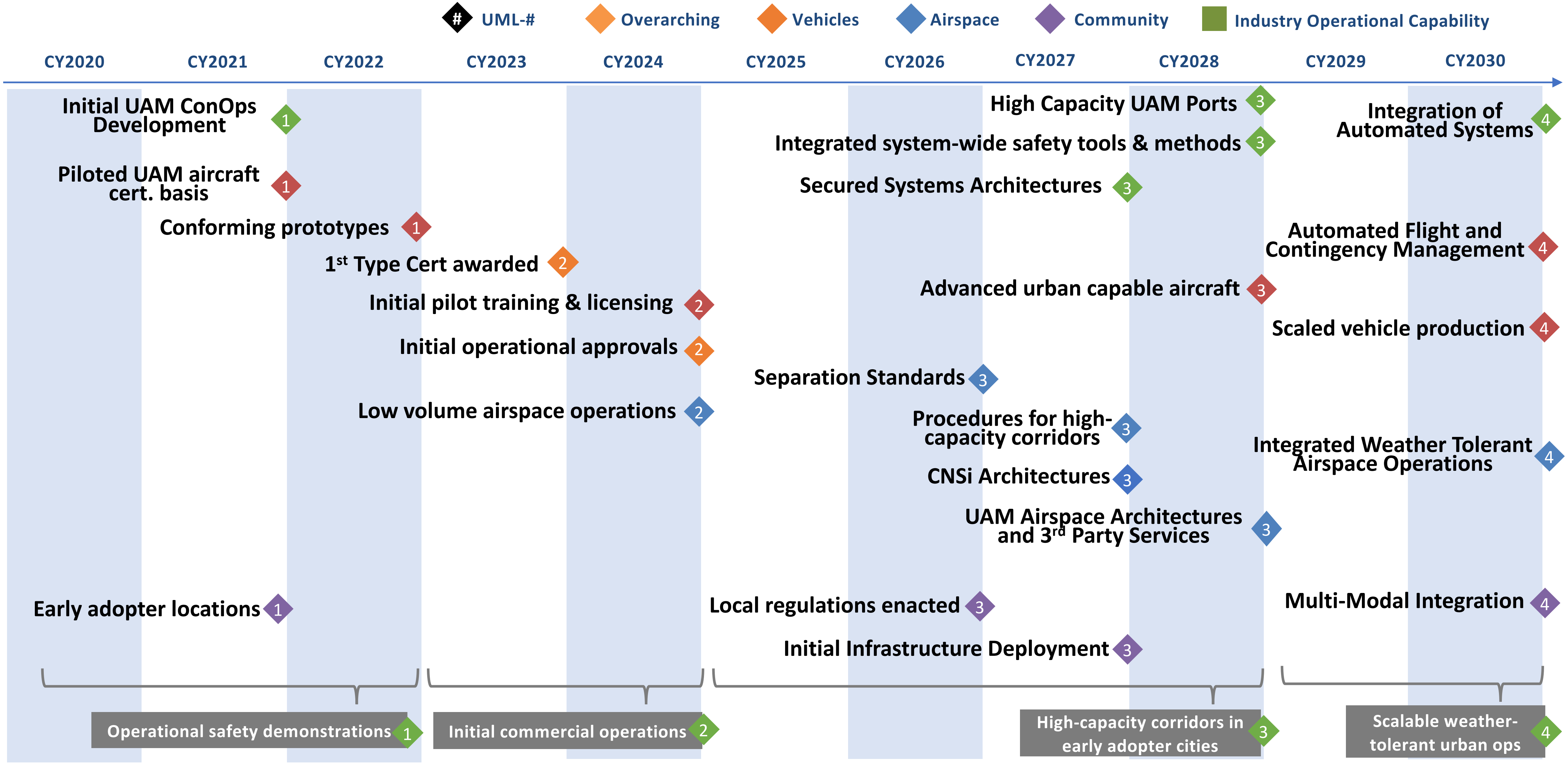


# Potential Multi-Facet Capability Maturity Efforts (Epochs)



# Supporting Slides

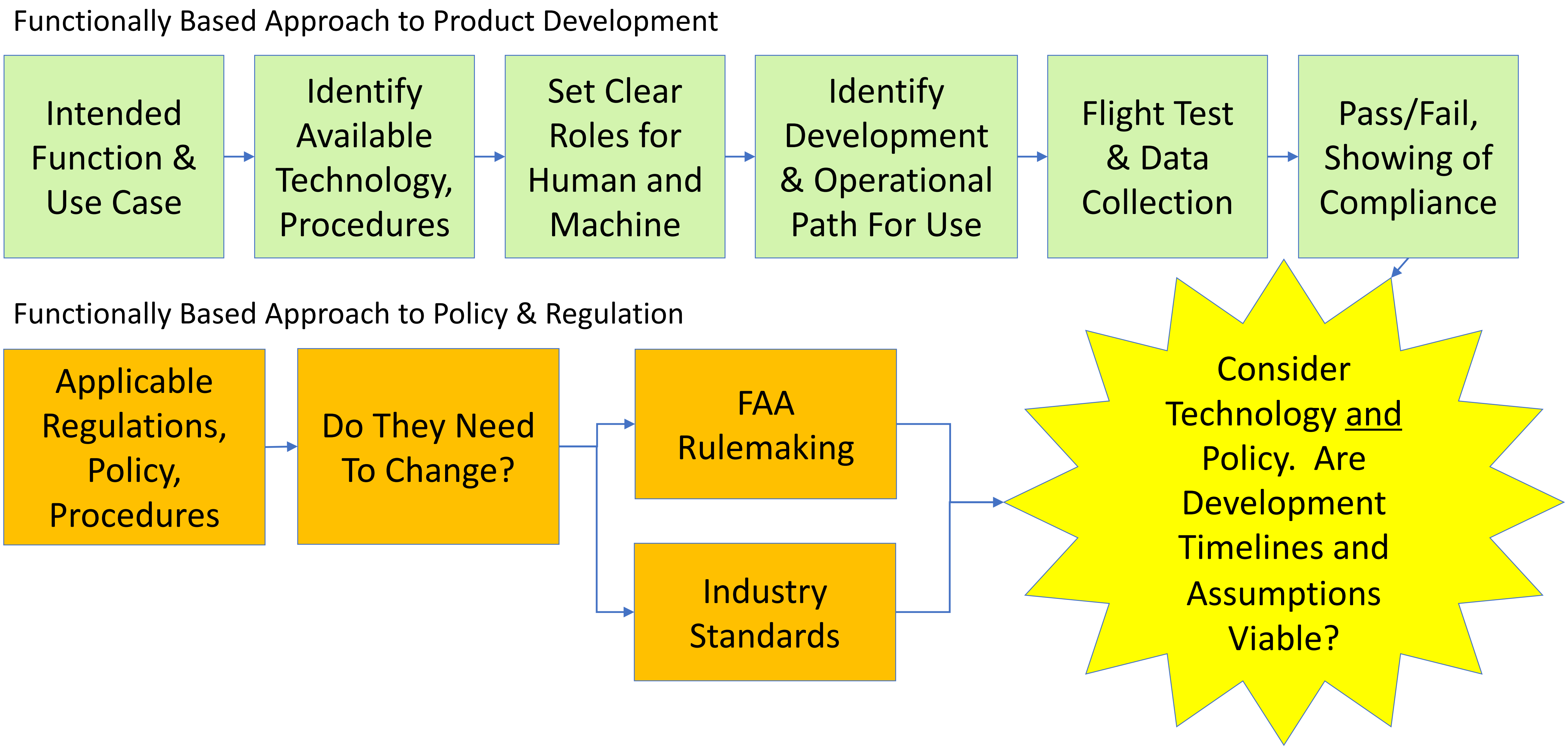
# Urban Air Mobility (UAM) Ecosystem Goals[1]




[1] Based on a range of publicly available industry projections; not a consensus view; aggressive

CNSi: Communication, Navigation, Surveillance, Information
UML: UAM Maturity Level

# Deconstruction of Functional/Technology Capability

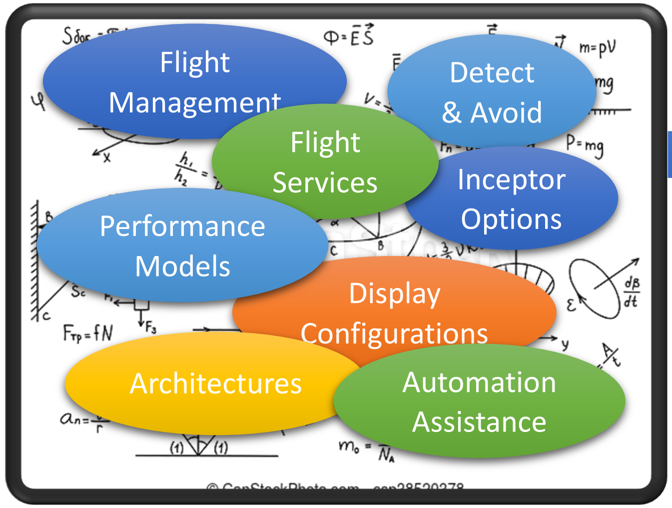


# Proposed Gated Process for Evaluating Capability/Function/Technology/Data

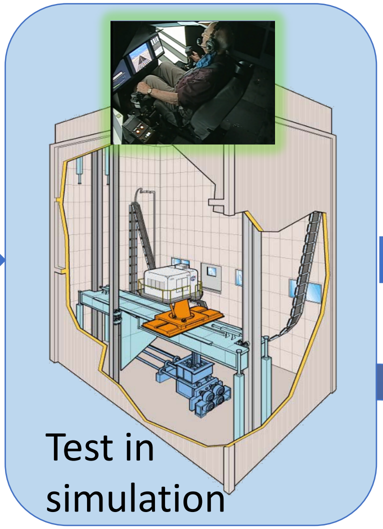
| Gate | Action/Evaluation |
|---|---|
| 0 | Identify an intended function for automation including the context – Intended use (e.g. operational context and/or phase of flight, and functional interfaces/dependencies) |
| 1 | Explain the potential benefits or incentives of automating the proposed function (e.g. safety enhancement, operational enhancement, and economics). Identify any potential risks, limitations, or barriers to automating the proposed function |
| 2 | Define how the intended function is currently completed/accomplished in operations and describe how it would be completed/accomplished once automated. Include human responsibilities and authority and how they could change and other system interfaces or dependencies when comparing. |
| 3 | Define the required information, processing, and outputs necessary to automate the function. |
| 4 | Identify candidate example technology products that may be capable of automating the function |
| 5 | Identify gaps in the current technology products to perform the function, and what operations the current technology could enable now |
| 6 | Identify the required maturity level of a technology product for it to achieve the intended function. Describe any differences in the level of maturity that may be appropriate depending upon aircraft size (i.e., normal category, transport category), kind of operation (i.e., cargo, passenger-carrying), or any other appropriate risk consideration. |
| 7 | Identify a path from current technology capabilities to the future technology capabilities necessary to achieve the identified maturity level(s). |
| 8 | Identify the applicable regulations/policy/standards/guidance (i.e., aircraft certification, operational, airman, ICAO) related to the current function. |
| 9 | With reference to Gates 2 and 8, identify what regulations/policy/standards/guidance may need revision and where new regulations/policy/standards/guidance may need to be developed to certify an aircraft with the technology and authorize/enable its use in operations. |

# Capability Maturation Process – NASA Example


Technical Challenge:
*Develop and evaluate an initial, integrated suite of key automation functions to enable simplified piloting in urban environments and propose recommendations to enable certification and approvals for the selected concepts.*




Use industry-representative models & technologies




Validate in flight
National Campaign (NC)/Integrated Automated Systems (IAS)

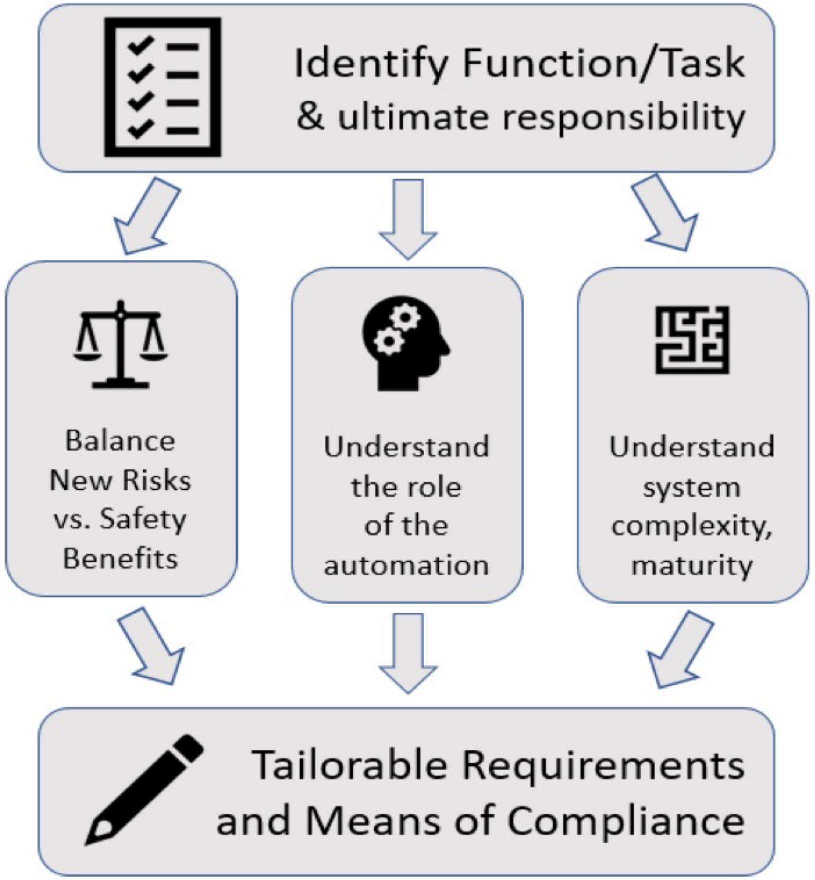
Capture Requirements

Identify common techniques for evaluation of performance, handling and safety

Deliver findings to inform development of System Concepts, Standards, Certification requirements and Means of Compliance

# Capability Maturity Model – Industry View

- Introduce Automation In Low-Risk Use Cases First, Where Appropriate
- Collect Data & Use Data to Develop/Validate Models
- Analyze Models for Higher Risk Safety Cases to Evolve
- "Build a Little, Test a Little" - Iterative Loop
- Models for Physical Problems Easier to Develop/Mature Than Models for Decision Making and Perception Functions
- Move Technical Maturity Forward for Specific Functions – Combine Functions to Reach Specific Operational Goals for Autonomy




From ASTM AC 377 TR

# Capability Maturity Challenges for UML-4 (NASA)

**UML 1 & 2**

**Initial certifications, revenue operations**

**Goals:** Certify base aircraft, approval for and initiation of revenue ops.

**Assumptions**: Highly experienced pilots. Low-tempo ops, VFR/VMC, current ATC

**Challenges**

- Define standards and methods of compliance for initial, highly-augmented aircraft
- Pilot requirements for add-on eVTOL rating must be developed
- Develop flight procedures compatible vehicle performance and automation

**UML 3**

**Technology and operational maturation**

**Goals:** Local network expansion in early markets while developing, maturing, validating technology/procedural foundations for scalable ops

**Assumptions:** Experienced pilots, locally-medium densities, VFR/VMC, NextGen UAM ConOps

**Challenges**

- Initial integration of flight path manage-ment automation with service provider network for strategic deconfliction and scheduling
- Maturation of 4D RNP TBO and automation for urban operations
- Development of comprehensive hazard perception and avoidance (HPA) for safety and airborne separation mang.
- Introduction of automated monitoring and management of mission and contingency planning to support pilot decision making, automate execution

**UML 4**

**Scalable systems and operations**

**Goals:** Scalable operations in IMC and util-zing less experienced pilots. Validate technology & standards for remote-PIC

**Assumptions:** Ab-initio commercial pilots, locally dense ops, IMC, UML-4 ConOps

**Challenges**

- Community consensus on scalable ConOps, architecture, interoperability
- Harmonization of aircraft automation standards, interfaces, assurance for nationally/ internationally scalable UAM
- Development of visibility independent flight rules and operations supported by integrated, air and ground automation
- Development of revised minimum pilot qualifications for UAM operations employing min. automation capabilities
- Validation of automation capabilities, standards, assurance, and human-interaction consistent with remote-PIC

Highlights indicate areas where Capability/Functions/Technology/Data and Regulatory Maturity are still unknown.

# Capability Maturity Challenges for UML-4

| Airspace Operations | CNS Infrastructure | Information Exchange | Ecosystem Engagement | Workforce & Staffing | Policy & Regulation |
|---|---|---|---|---|---|
| Identify and implement future UAM requirements to airspace and air traffic modernization programs such as airspace design, flow management, trajectory-based operations, performance-based navigation, and procedures and standards. | Partner with appropriate stakeholders to develop and validate requirements and integrate the full life-cycle of UAM- enabling Communication, Navigation, and Surveillance, (CNS) and other UAM NAS infrastructure. | Incorporate UAM requirements and concepts into ATO automation and data modernization activities as part of a UAM enabled information centric NAS. | Collaborate with local, state, municipal and tribal government entities, industry, academic and international stakeholders to address the challenges of UAM, coordinate on strategies and approaches, and communicate progress to build a coordinated approach to UAM Airspace integration. | Build, empower, and retain adaptive talent to effectively anticipate and address evolving UAM workforce needs. | Identify, develop, and publish timely, iterative, policy and regulation to enable the safe implementation of UAM. |

Highlights indicate areas where Capability/Functions/Technology/Data and Regulatory Maturity are still unknown.

# Progressive Task-Based Development

- Identify Mature Technology to Perform Specific Functions
- Automate Mature Functions First
- Human Pilot Remains Responsible for Fewer and Fewer Functions as Automation is Introduced Safely
- Human May Always Be Needed for Contingency Management and Overall Safety of Flight

**Buildup Progression**

| Phase (MTE) | Function | Current Part 91 | Current Aircraft | Step A | Step B | Step •••• | Step •••• | Step ? |
|---|---|---|---|---|---|---|---|---|
| ALL Phases | Contingency | Pilot | Pilot | Pilot | Pilot | Pilot | Pilot | Auto? |
| Preflight | Flight Plan | Pilot | Pilot | Pilot | Pilot | Auto | Auto | Auto |
| Preflight | Walk around | Pilot | Pilot | Pilot | Pilot | Auto | Auto | Auto |
| Ground Ops | Taxi | Pilot | Pilot | Pilot | Auto | Auto | Auto | Auto |
| Takeoff | Takeoff | Pilot | Pilot | Pilot | Auto | Auto | Auto | Auto |
| Enroute | Aviate | Pilot | Pilot | Auto | Auto | Auto | Auto | Auto |
| Enroute | Navigate | Pilot | Pilot | Pilot | Auto | Auto | Auto | Auto |
| Enroute | Communicate | Pilot | Pilot | Pilot | Pilot | Pilot | Auto | Auto |
| Enroute | VFR-like Separation | Pilot | Pilot | Pilot | Pilot | Pilot | Auto | Auto |
| Approach | Approach | Pilot | Pilot | Pilot | Pilot | Auto | Auto | Auto |
| Approach | Missed | Pilot | Pilot | Pilot | Pilot | Auto | Auto | Auto |
| Landing | Landing | Pilot | Pilot | Pilot | Pilot | Pilot | Auto | Auto |

# Capability Maturation Between Epochs

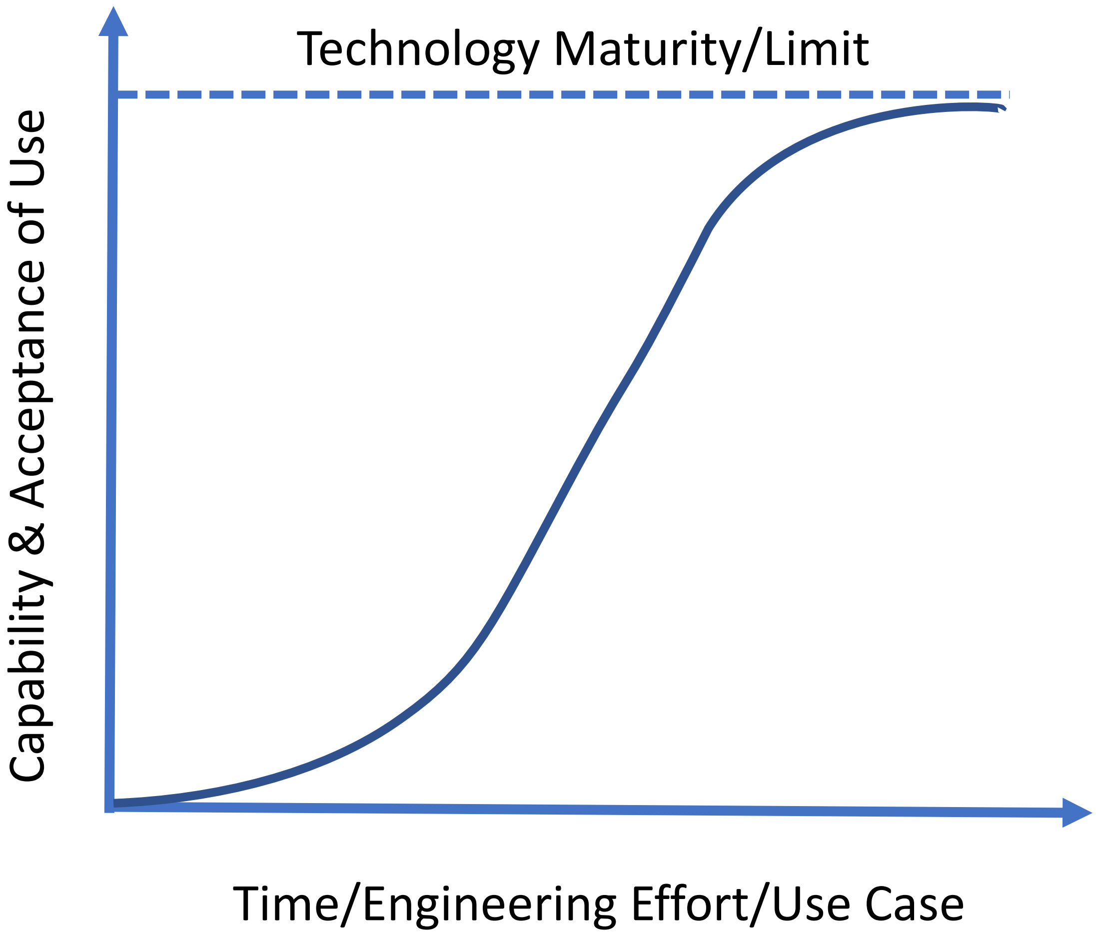
| Epoch 1 | Enabler, Barrier, R&D Opportunity | Epoch 2 |
|---|---|---|
| Automation Concepts for Nominal Control/Behavior | Tech Enabler | Design Redundancy and Architectural Lessons Learned – Behavior-based Outcomes/Rules |
| Automation Concepts for Safe Reversionary Control/Contingency | Tech Enabler | Design Redundancy and Architectural Lessons Learned – Behavior-based Outcomes/Rules |
| Part 107 | Reg Barrier | Part 91 |
| Segregated Airspace | Reg Barrier | Integrated Airspace |
| No Airworthiness | Reg Barrier | Part 21 Airworthiness |
| VLOS & Obstacle Masking | Tech & Reg Barrier | 91.113 Required |
| Proximity to Objects | Tech Barrier | Sensors for Tactical Detection |
| Small Size – Ground Risk | Tech & Reg Barrier | Must Mitigate Ground Risk |
| Small Sphere of Influence | Tech & Reg Barrier | Contingency Management |
| Close Sensor Range | Tech Barrier | Closure Rates/Distances - Sensors Not Ready |
| | | |
| | | |

# Capability Maturity Between Epochs

| Epoch 1 | Enabler or Barrier | Epoch 2 |
|---|---|---|
| Automation Concepts for Nominal Control/Behavior | Tech Enabler | Design Redundancy and Architectural Lessons Learned – Behavior-based Outcomes/Rules |
| Automation Concepts for Safe Reversionary Control/Contingency | Tech Enabler | Design Redundancy and Architectural Lessons Learned – Behavior-based Outcomes/Rules |
| Part 21 OPA Airworthiness | Reg Enabler | Part 21 Airworthiness |
| Part 91, Pilot Mostly On Board or Visual Observer Requirement if Off-Board | Tech & Reg Barrier | Part 91 – 100% Remote Pilot – 91.113 compliance and acceptable MOC to AFS/ATO |
| Integrated Airspace – Pilot on Board & OPA Procedures Meet 91.113 | Tech & Reg Barrier | Integrated Airspace – Remote Pilot & Technology Must Meet 91.113 |
| Sensors for Assistive Tactical Detection - Pilot Primary for 91.113 Compliance | Tech Barrier | Sensors for Safety Critical Tactical Detection – Remote Pilot 91.113 Compliance Unclear |
| Must Mitigate Ground Risk – Optional Pilot May Play into Mitigation | Tech & Reg Barrier | Must Mitigate Ground Risk – Remote Pilot Role Undefined for MOC for Mitigation |
| Large Aircraft Risk to Airspace/Others Mitigated by OPA Procedures and/or Pilot On Board | Tech & Reg Barrier | Contingency Management by Remote Pilot in Manner Acceptable to AFS/ATO |
| Closure Rates/Distances - Sensors Not Ready for Safety Critical Use | Tech & Reg Barrier | Sensors Expected to Replace Pilot Vision for 91 Compliance – MOC Acceptable to AFS/ATO |

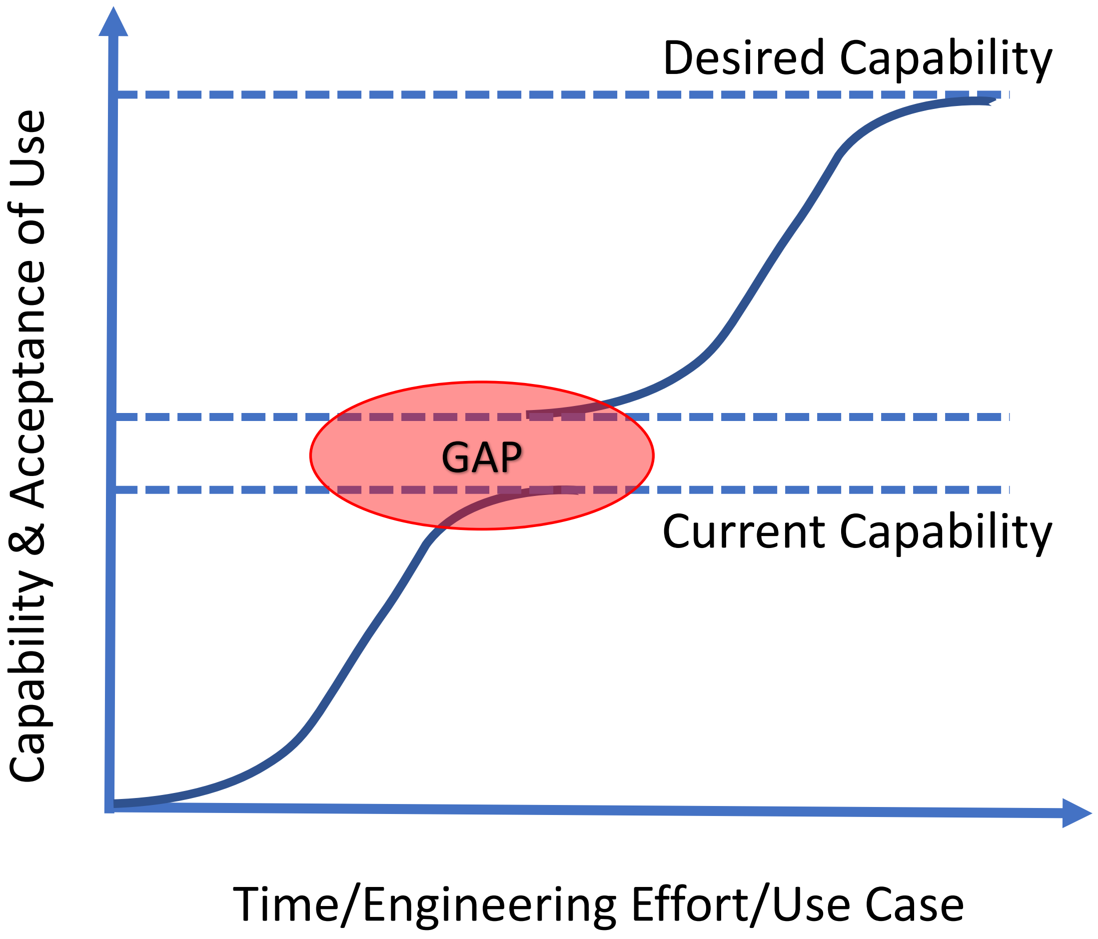
# S-Curve of Technology Maturation

- Initial Development/Capability Slow
- Build Lessons Learned and Experience
- Maturity Leads to Greater Capability and Accepted Use
- Technology Reaches a Limit of Capability
  - Based on Assumptions for Development
- Capability Limits Spawn New S-Curves for Next Generation and/or Expanded Development for New Use Cases

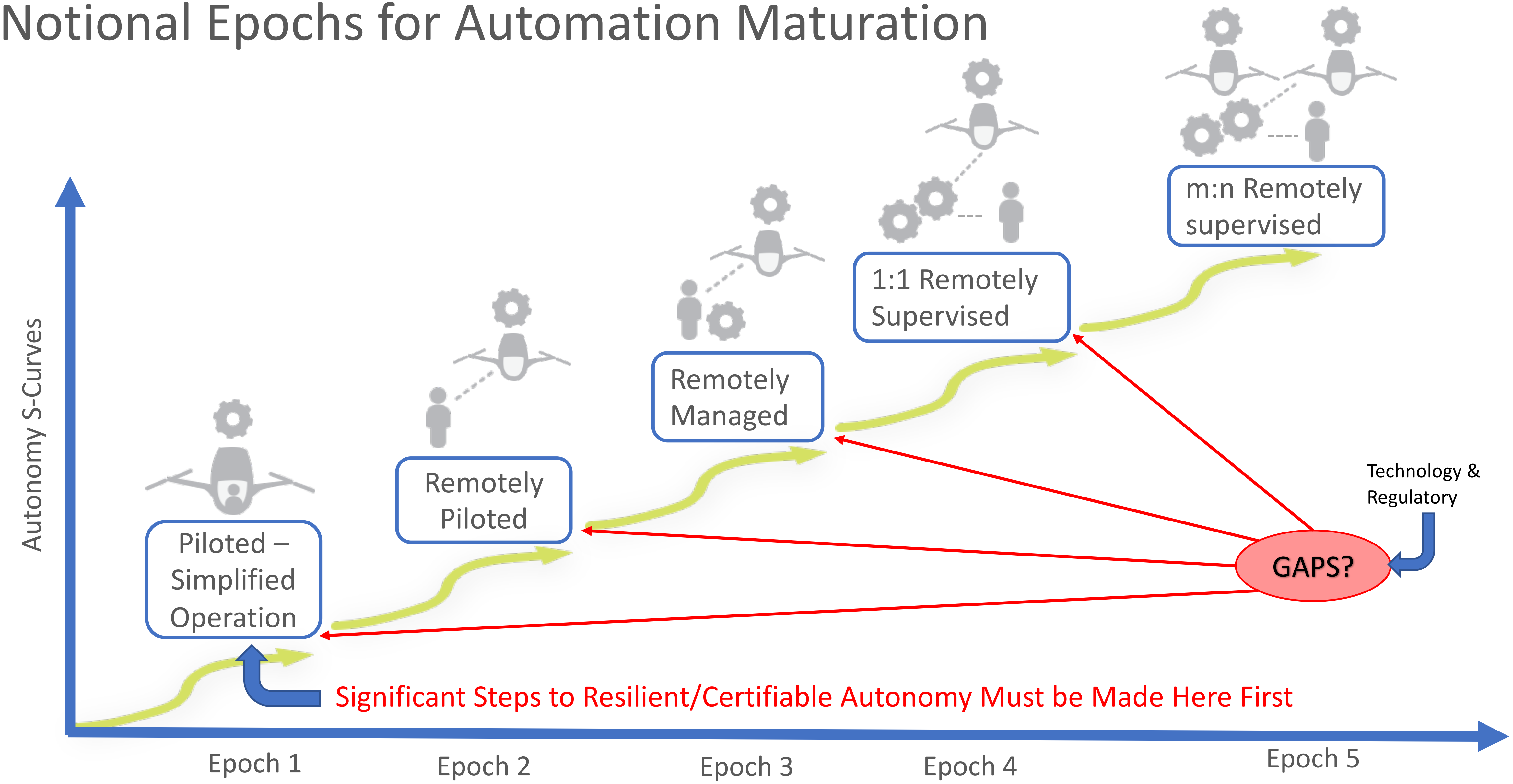


# S-Curve Epochs – Maturity & Discontinuity

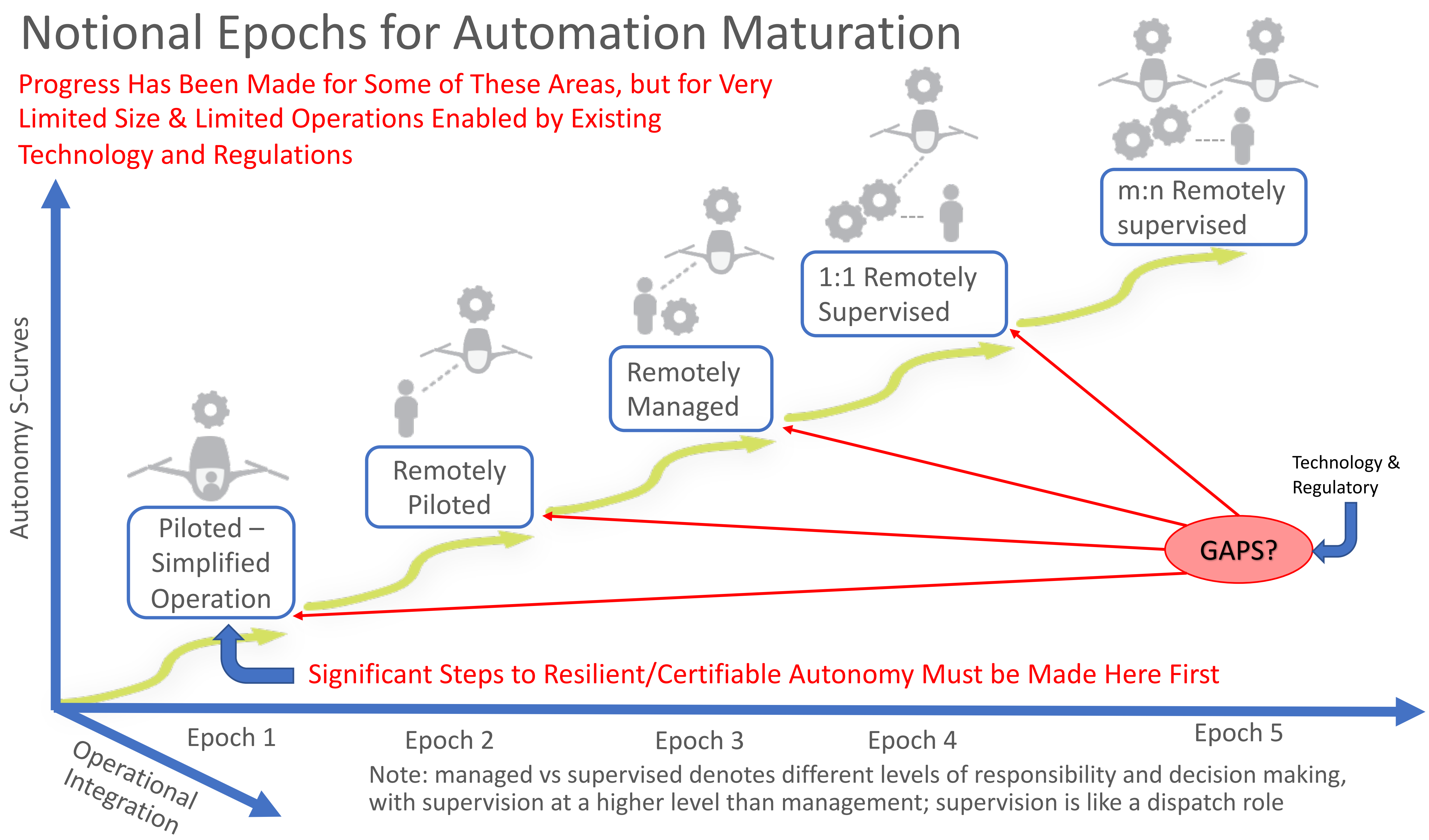
- Gaps in Capability May Limit Growth Towards Ultimate Goal/Use Case
- Gaps Can Exist in Technology, Regulation, and/or Operational Capability
- Consider the Level of Expected Integration vs. Demonstrated Capability
- Technology Gaps Must be Overcome by Data Collection and Demonstration in Real-World Scenarios – Catch 22
- Regulatory Gaps Present Similar Challenge - Overcome by Data



# Notional Epochs for Automation Maturation




Note: managed vs supervised denotes different levels of responsibility and decision making, with supervision at a higher level than management; supervision is like a dispatch role


Notional Epochs for Automation Maturation
Progress Has Been Made for Some of These Areas, but for Very Limited Size & Limited Operations Enabled by Existing Technology and Regulations
m:n Remotely supervised
1:1 Remotely Supervised
Remotely Managed
Remotely Piloted
Piloted – Simplified Operation
Technology & Regulatory
GAPS?
Autonomy S-Curves
Significant Steps to Resilient/Certifiable Autonomy Must be Made Here First
Epoch 1
Epoch 2
Epoch 3
Epoch 4
Epoch 5
Operational Integration
Note: managed vs supervised denotes different levels of responsibility and decision making, with supervision at a higher level than management; supervision is like a dispatch role

# Industry Challenge – Separate Efforts

- Many Solely Focus on Technology Readiness and Concern About Regulatory Readiness
  - Regulatory Change Requires Data - Change Needed Before Some Concepts Can Be Certified.
  - Assurance And Trustworthiness – What Role Would Surrogate Aircraft Play In Technology/Operational Maturation?
  - Current Design/V&V Practices May Need To Evolve
- Each is Working To Design Task-based Automation Towards Future Autonomy for their Use Case
  - How To Methodically Evolve to New Roles for Humans Envisioned for UML-4, 5, 6?
  - Architecture And Resilient Proficiency – How To Design Architectures Where The Human Is No Longer Critical
  - Design for Unforeseen Circumstance –Design for “Mission-Intent Level Outcomes”

# Focus on Behavior/Rule Based Outcomes

- Pass/Fail Criteria for Specific Tasks
- Focus on Intended Function
- Build In, Test Proficiency & Robust Function
- Criticality Only Increases as S-curve Reaches Maturity